Updates to ESRL's FIM-Chem global modeling system and comparison of aerosol optical depth forecasts with AERONET observations

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And many FIM developers

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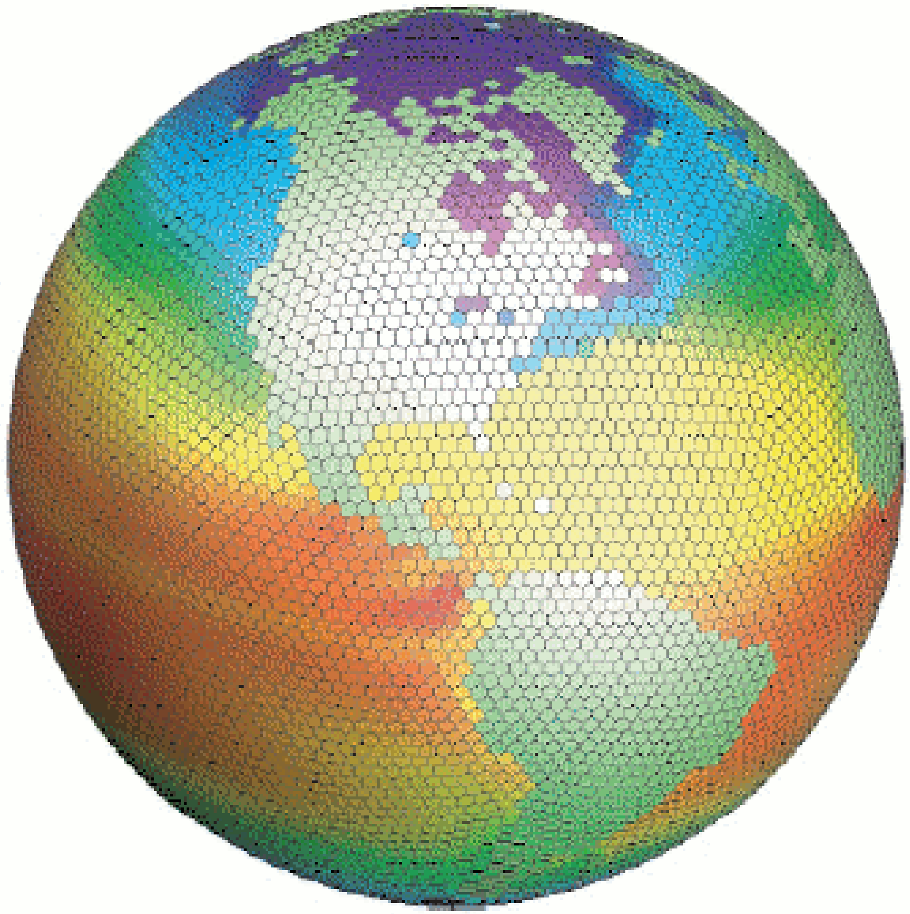
Outline

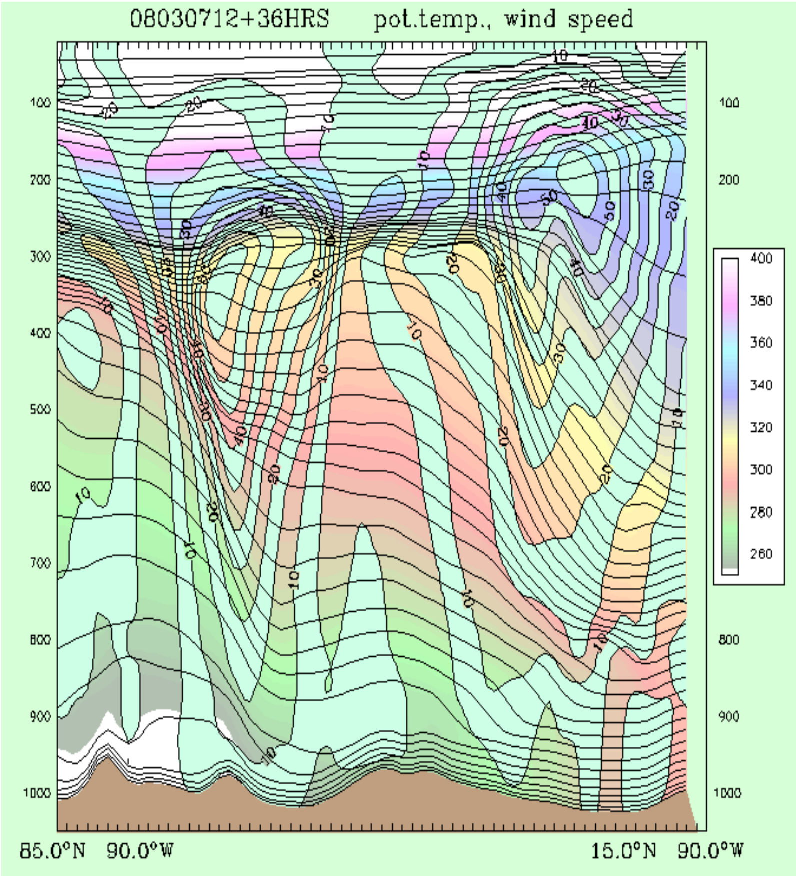
- Some slides on FIM-Chem development
- Evaluation with AERONET data
- Future plans

FIM: Flow-following- finite-volume Icosahedral Model

Icosahedral horizontal grid



Nearly equal size of grid volumes, including near poles

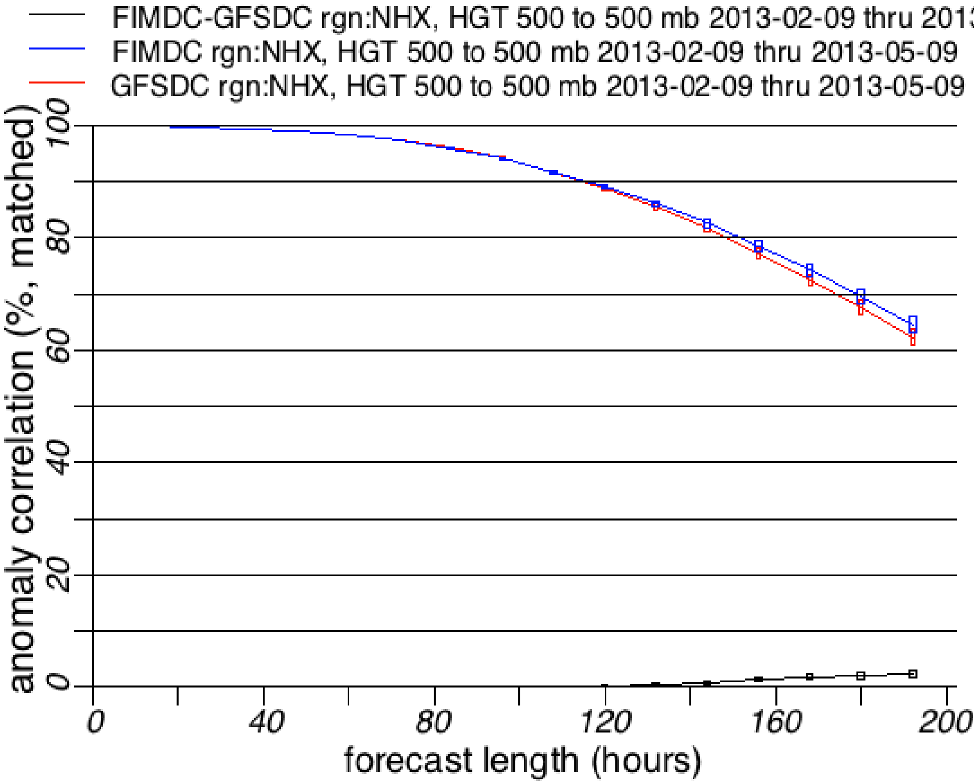


Hybrid (sigma/ isentropic) vertical coordinate

- Improved conservation using quasi-material surfaces, reduced vertical dispersion. Improved stratospheric/tropospheric exchange

Physics in FIM

- Initially: GFS physics. Immediate goal for FIM is contributing dynamical-core diversity to NCEP Global Ensemble Forecast System
- Need to show that FIM is at least comparable in skill to GFS
- From Weather Research and Forecasting Modeling system (WRF): Cumulus parameterizations and microphysics routines may be used
- All Chemistry routines: From WRF



Current skill scores are slightly better than GFS

Chemistry: what is currently included (running in real-time)

- Aerosol and simple sulfur chemistry modules from the Global Chemistry Aerosol Radiation and Transport (GOCART) model
- 4-bin sea-salt from GOCART
- 5-bin dust based on GOCART but after further development from AER/AFWA
- Wildfire plume-rise
- Volcanic ash and SO2 emissions, historic or in real-time
- Dry and wet deposition, sub-grid scale transport

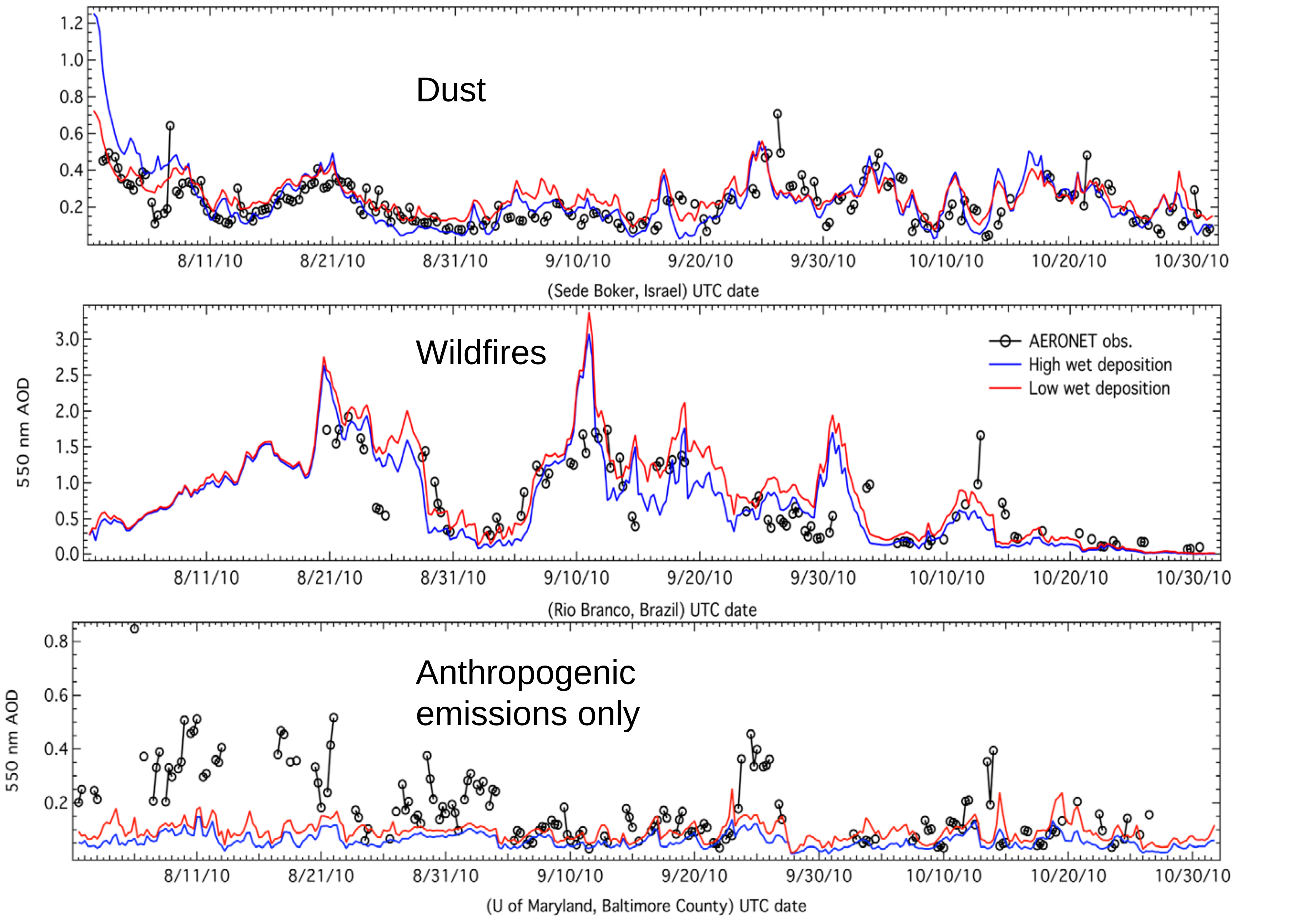
Aerosol direct and semi-direct effect through interaction with radiation (online MIE calculations)

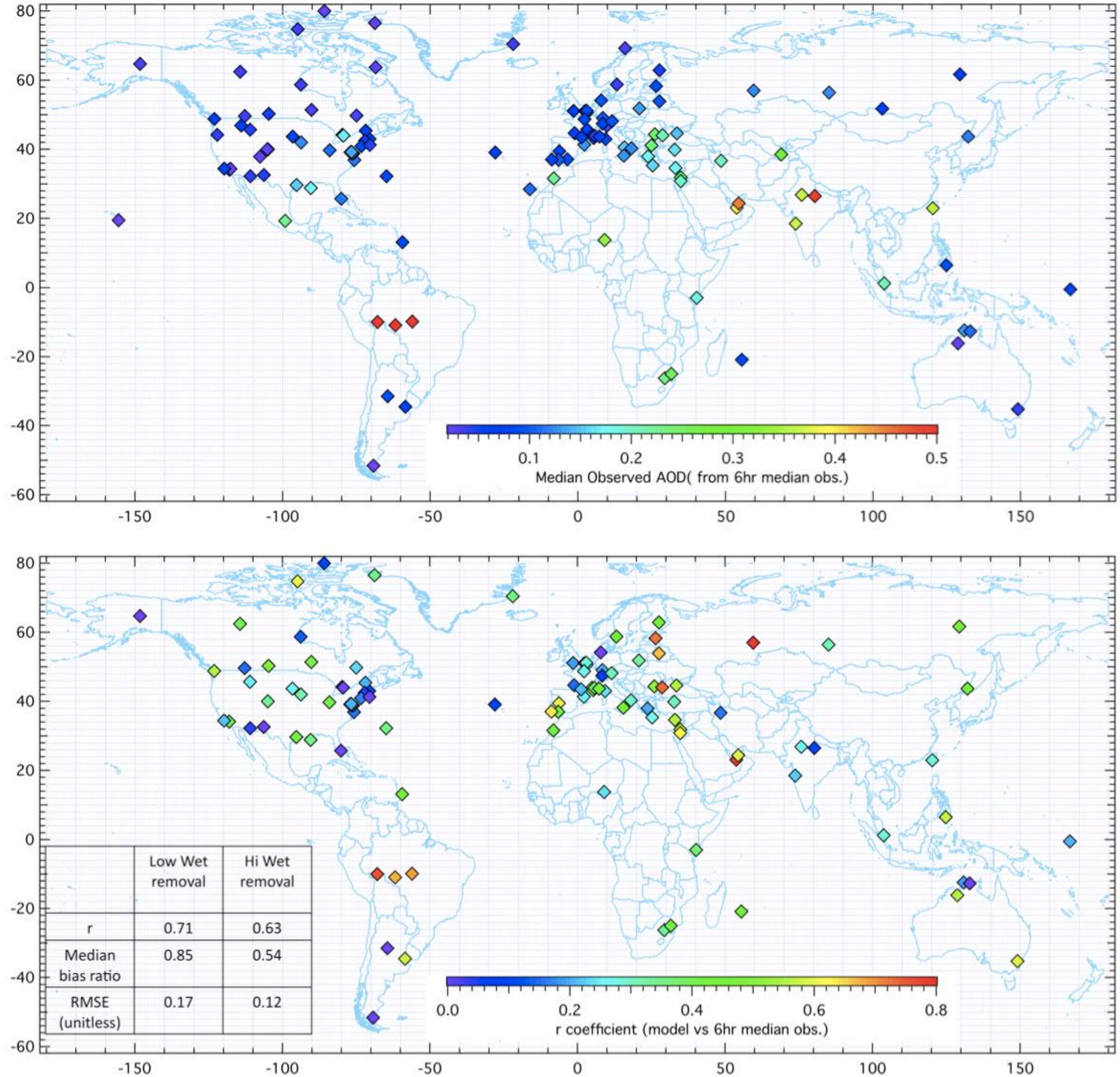
Simulating aerosol optical properties (AFWA project)

- Three month period in 2010 to evaluate AOD predictions from FIM-Chem, 60 km global resolution, 2 runs per day for 24-hr forecasts, aerosols are cycled
  - GOCART aerosol modules, but new AFWA/AER dust model
  - Dust and sea-salt emissions online, anthropogenic emissions from RETRO/EDGAR .25 degree resolution global data set, fires from MODIS Satellite data
  - Comparison to AERONET observations as well as Satellite observations
- 10 years of runs for AFWA
- Optical routine that uses FIM-Chem and/or WRF-Chem output to provide aerosol optical properties and phase functions

10-year data set available for further examination

Time-series comparisons for 2 different FIM-Chem runs, August – October 2010



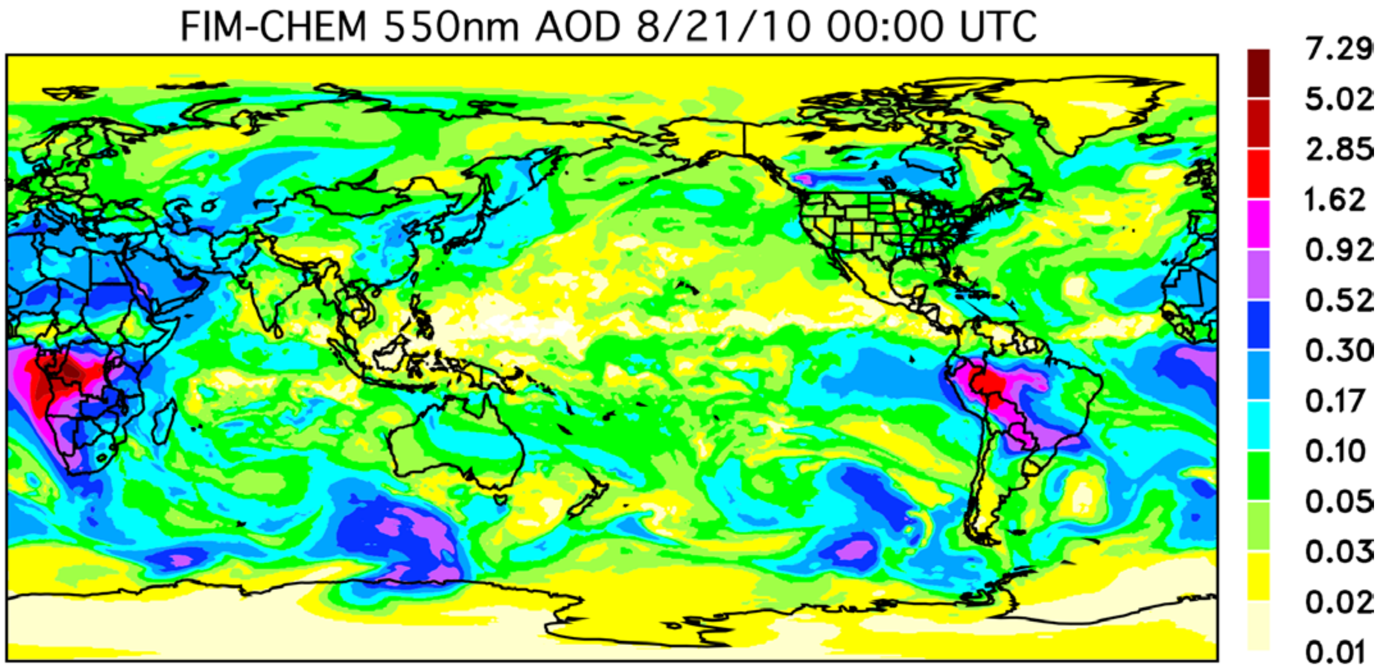


	Low Wet removal	Hi Wet removal
r	0.71	0.63
Median bias ratio	0.85	0.54
RMSE (unitless)	0.17	0.12

Comparison with AEONET data, August through October 2010, 24 hr forecasts, 11835 points

No chemical data assimilation yet !!

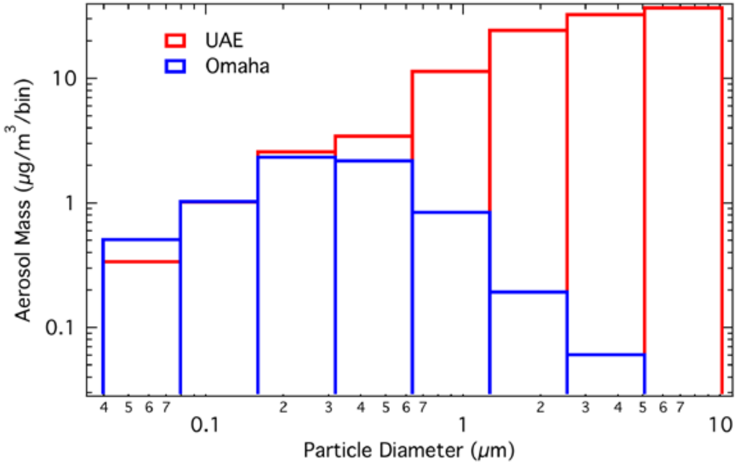
Example of Optics at 2 very different locations: Omaha Nebraska, and United Arab Emirates

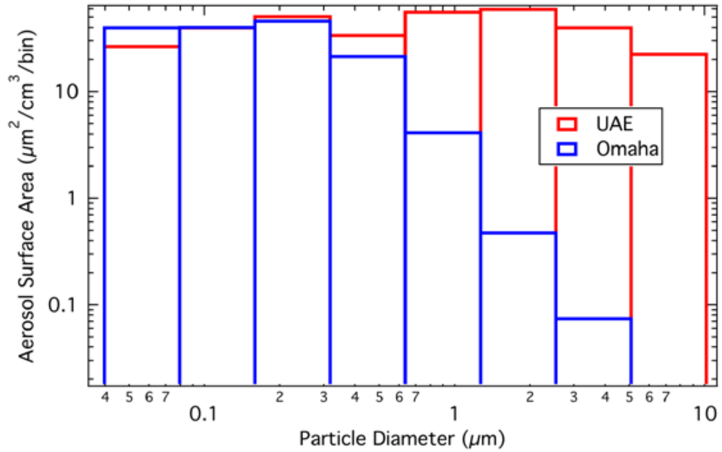


550nm AOD	
Omaha	0.07
UAE	0.41

(400m ASL) Omaha: $PM_{2.5}$= 6.57 µg/m^3, mostly Sulfate, with some Organics, Primary (unspeciated)

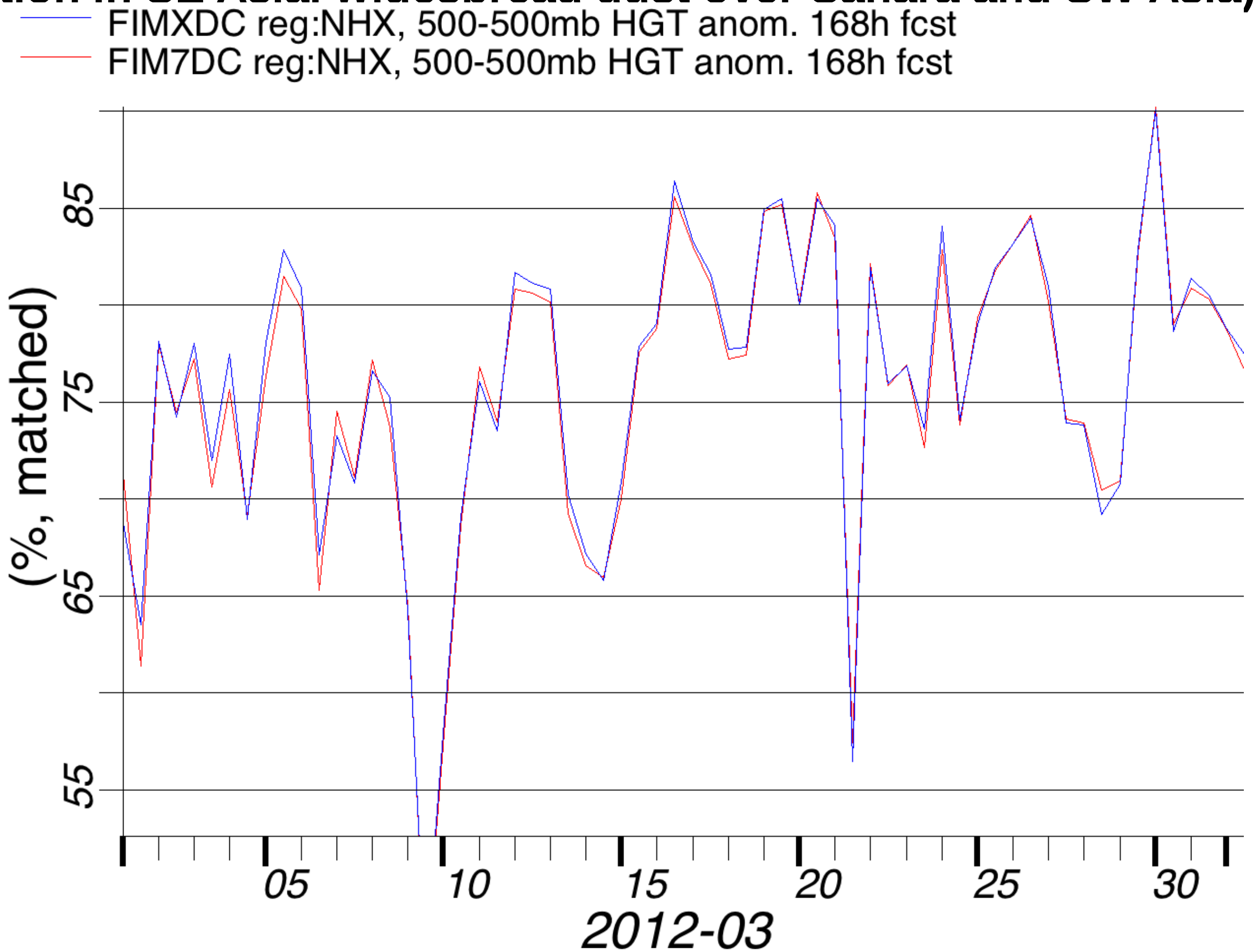
United Arab Emirates: $PM_{2.5}$= 65.8 µg/m^3, mostly Dust, a little Seasalt, and Sulfate





Some impact on weather forecast in real-time runs, even without data assimilation and/or tuning

Spring 2012: Largest impact in Northern Hemisphere (fires and air pollution in SE Asia, widespread dust over Sahara and SW Asia)



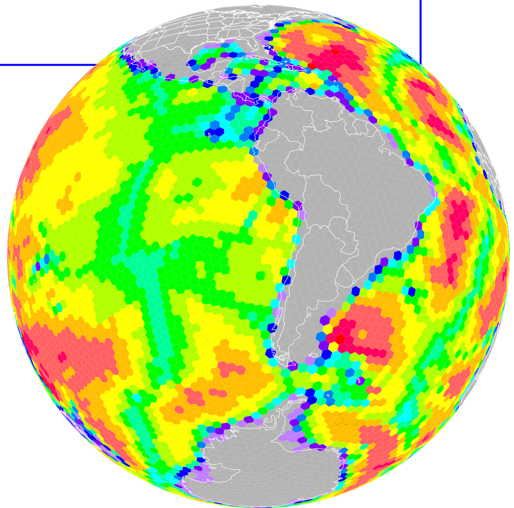
500 hPa height anomaly correlation verification score - 7-day forecasts

Currently in progress future model development

- Significant effort towards implementing data assimilation
- Mariusz Pagowski is working on both, NCEP's 3DVAR Grid point Statistical Interpolation (GSI) system as well as the EnKF approach developed by T. Hamill and J. Whittaker here at ESRL
- The EnKF approach already works with WRF-Chem for AOD and in-situ observations. The plan is to use for FIM-Chem with AOD and/or AAOD

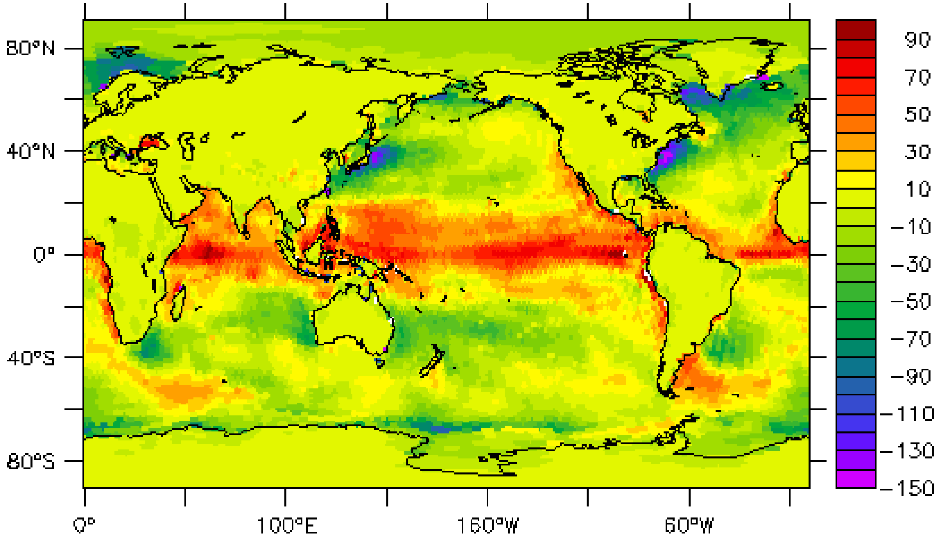
- FIM was coupled with icosahedral version of HYCOM Ocean model and is currently being tested

Icosahedral Ocean Model (iHYCOM)



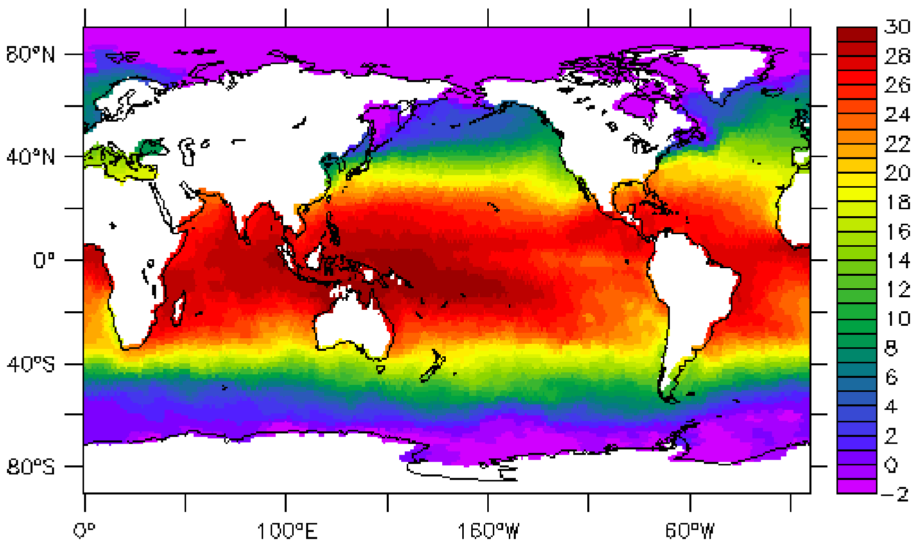
Coupled FIM & iHYCOM g5

surface net heatflux (W/m2, positive down)

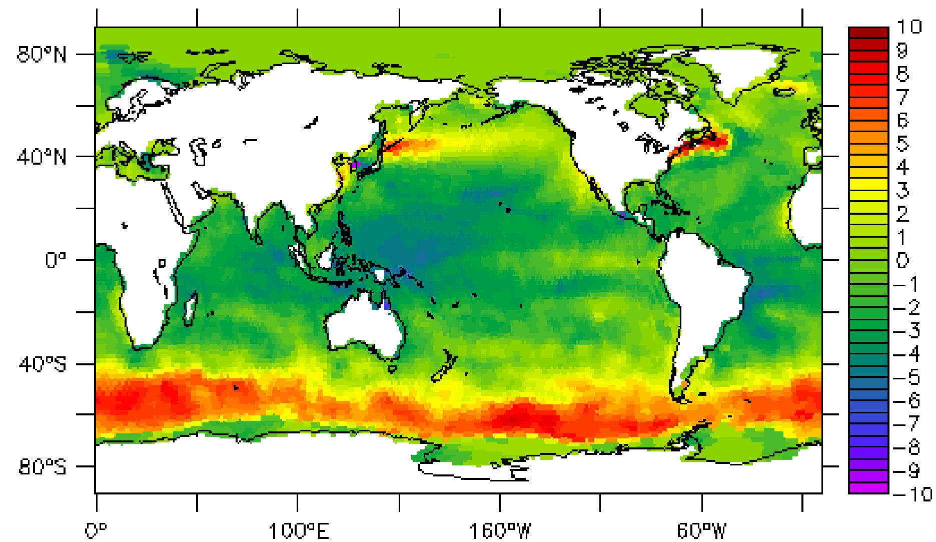


The global annual net heatflux at the surface is close to zero in the coupled FIM atmospheric model and the iHYCOM ocean model. However, the regional biases in the ocean mixed layer temperature are too big. Investigation in radiation/cloud physics is going on.

initial ocean mixed layer temperature



mixed layer temperature 1 year minus initial



Currently in progress future model development

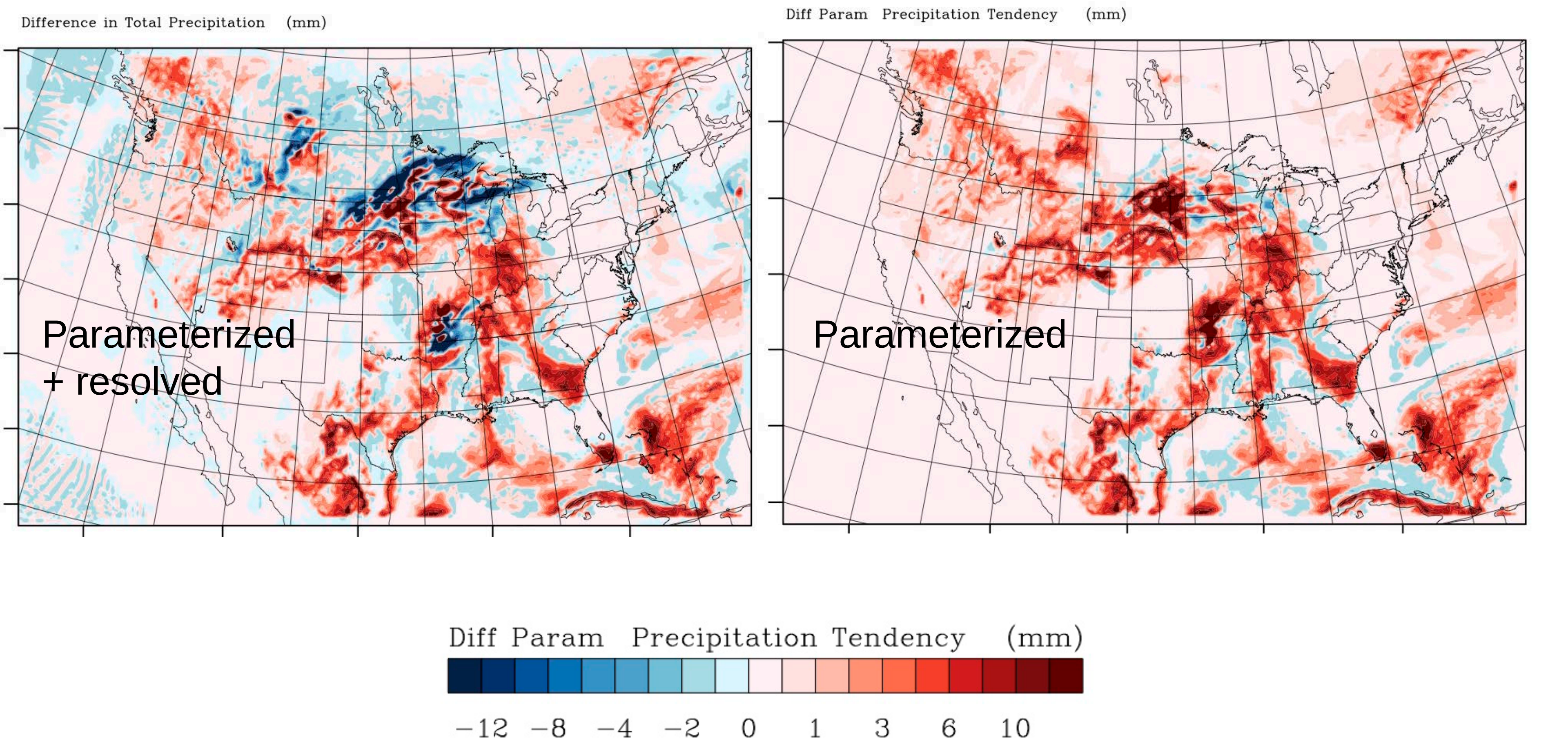
- Improving emissions: implementing regional data sets, already done for SE Asia (by Li Zhang)
- A Convective parameterization that allows for aerosol indirect effect and smooth transition to cloud resolving scales (Grell and Freitas)
- Plumerise for wildfires will be dependent on windshear

Transition to non-hydrostatic model (no scale restriction) will also be coming, several version are already being tested here at ESRL as well as NCAR: NIM (ESRL development) and MPAS (NCAR)

The new GF scheme:

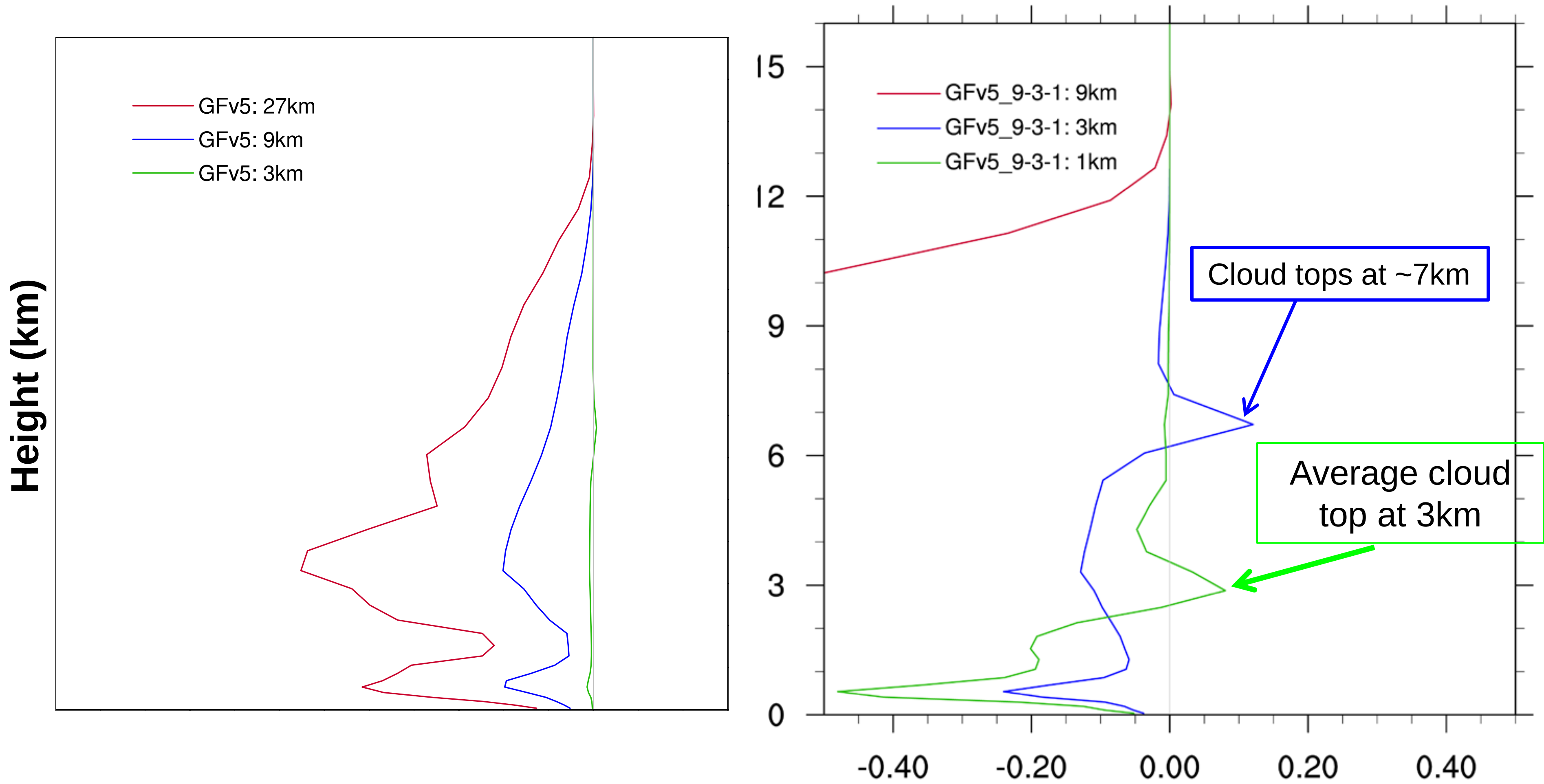
- Use forcing ensembles (stability equilibrium, stability removal, low level vertical velocity, integrated moisture convergence)
- Random number generator to perturb ensembles or use stochastic field to perturb ensembles or fields that forcing depends on
- Entrainment/detrainment rates have been adjusted to give smooth normalized mass flux profiles (parabolic start-up and end).
- Depending on surface heat and moisture fluxes, CAPE may optionally be increased or decreased similar to the method described in Jakob and Siebesma (2003)
- Arakawa et al (2011) approach or subsidence spreading may be used for scale aware approach
- GF may also use aerosol effect, transport of tracers, wet deposition, aqueous phase chemistry
- **Aerosols may interact through conversion rate of cloud water to rainwater as well as evaporation of raindrops**

Example of aerosol interactions (Cumulus parameterization) with WRF simulations, difference fields of accumulated total and parameterized precipitation (clean – polluted)



Dx=20 km

Smooth transition to cloud resolving scales: Idealized hurricane simulations with WRF, dx=27-9-3-1km



Drying tendencies at 36hr (deg/day) – averaged inner part of 1km domain

The 1D cloud model: including the environmental wind effect on cloud scale dilution- governing equations

dynamics for W

$$\frac{\partial w}{\partial t} + w\frac{\partial w}{\partial z} = \gamma g B - \frac{2\alpha}{R} w^2 - \delta_{entr} w$$

dynamics for U

$$\frac{\partial u}{\partial t} + w\frac{\partial u}{\partial z} = -\frac{2\alpha}{R}|w|(u-u_e) - \delta_{entr}(u-u_e)$$

thermo-dynamics

$$\frac{\partial T}{\partial t} + w\frac{\partial T}{\partial z} = -w\frac{g}{c_p} - \frac{2\alpha}{R}|w|(T-T_e) + \left(\frac{\partial T}{\partial t}\right)_{micro-physics} - \delta_{entr}(T-T_e)$$

water vapor conservation

$$\frac{\partial r_v}{\partial t} + w\frac{\partial r_v}{\partial z} = -\frac{2\alpha}{R}|w|(r_v - r_{ve}) + \left(\frac{\partial r_v}{\partial t}\right)_{micro-physics} - \delta_{entr}(r_v - r_{ve})$$

cloud water conservation

$$\frac{\partial r_c}{\partial t} + w\frac{\partial r_c}{\partial z} = -\frac{2\alpha}{R}|w| r_c + \left(\frac{\partial r_c}{\partial t}\right)_{micro-physics} - \delta_{entr} r_c$$

rain/ice conservation

$$\frac{\partial r_{ice,rain}}{\partial t} + w\frac{\partial r_{ice,rain}}{\partial z} = -\frac{2\alpha}{R}|w| r_{ice,rain} + \left(\frac{\partial r_{ice,rain}}{\partial t}\right)_{micro-physics} + \text{sedim} - \delta_{entr} r_{ice,rain}$$

dynamic entrainment

$$\delta_{entr} = \frac{2}{\pi R}|u_e - u|$$

equation for radius size

$$\frac{\partial R}{\partial t} + w\frac{\partial R}{\partial z} = +\frac{6\alpha}{5R}|w| R + \frac{1}{2}\delta_{entr} R$$

bulk microphysics

$$\left(\frac{\partial \xi}{\partial t}\right)_{micro-physics} (\xi = T, r_v, r_c, r_{rain}, r_{ice}),\ \text{sedim}$$

bulk microphysics:
Kessler, 1969; Berry,1967
Ogura & Takahashi,1971

See Freitas et al. (2010 ACP) for 1d cloud model comparisons with fully 3D ATHAM simulations

Future model development, but not in progress yet

- Using physics and chemistry from NCAR climate model (also available through WRF-Chem)
- Ozone chemistry and biogenic emissions
- Aerosol indirect effect for microphysics

Questions?